

Research on the Integration and Innovative Application of Artificial Intelligence Technology in Mechanical Engineering Teaching

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Abstract: The rapid development of artificial intelligence (AI) technology has brought new possibilities for the systemic transformation of mechanical engineering education. Based on the teaching characteristics and era challenges of the mechanical engineering discipline, this paper systematically explores the integration paths and innovative application modes of AI technology in the teaching of the mechanical engineering major. Firstly, the study analyzes the practical background and core connotation of AI empowering mechanical engineering teaching and then constructs a theoretical framework for AI technology integration from four dimensions: curriculum system restructuring, teaching model innovation, experimental practice upgrading, and personalized learning support optimization. On this basis, the paper deeply discusses the key application scenarios, including curriculum content organization based on knowledge graphs, the human-machine collaborative classroom teaching paradigm, virtual-real integrated experimental practice ecology, and data-driven personalized learning support. Finally, the study probes into the challenges and corresponding strategies faced by the application of AI technology, aiming to provide theoretical reference and practical guidance for mechanical engineering educators to promote the digital transformation of teaching.

1. Introduction

1.1. Research Background and Problem Statement

At present, AI technology is reshaping the operational logic and development paradigm of all walks of life with an unprecedented depth and breadth. In the manufacturing industry, the wide application of technologies such as intelligent equipment, industrial Internet, and digital twin has put forward brand-new requirements for the knowledge structure and competency quality of mechanical engineering talents [1]. At the same time, AI technology itself provides powerful tool support for the transformation and upgrading of education and teaching [2]. Against the backdrop of this dual transformation, how to effectively integrate AI technology into the curriculum design and

teaching methods of the mechanical engineering major has become a core issue to be further explored in the field of engineering education.

As a typical representative of traditional engineering majors, the teaching system of mechanical engineering is characterized by the equal emphasis on theory and practice, a hierarchical and systematic knowledge system, and a prominent orientation towards engineering application. These characteristics not only provide abundant scenarios for the application of AI technology but also put forward higher requirements for the depth and appropriateness of technology integration. Practice has shown that after four stages of iteration, including "traditional blackboard writing—multimedia teaching—blended online and offline teaching—smart teaching," mechanical engineering courses are building a "teacher-student-machine" tripartite collaborative teaching ecology with the help of AI technology [3]. This transformation is not only an update of technical means but also a profound change in educational concepts and teaching paradigms.

1.2. Research Significance

This study aims to systematically explore the integration paths and innovative applications of AI technology in mechanical engineering teaching, and its theoretical significance lies in three aspects: first, constructing an AI technology integration framework tailored to the disciplinary characteristics of mechanical engineering and enriching the theoretical system of digital transformation in engineering education; second, exploring the internal mechanism of the deep integration of AI technology and mechanical engineering teaching and revealing the possible boundaries and realization conditions of technology empowering education; third, promoting the deepening and expansion of educational technology research from the level of instrumental rationality to the level of teaching paradigm.

Its practical value is reflected in providing systematic methodological guidance for mechanical engineering teachers to understand and apply AI technology to optimize teaching; offering referable implementation paths for curriculum directors to promote the intelligent transformation of courses; and supplying decision-making references for university teaching managers to formulate AI-empowered education development strategies.

2. Theoretical Foundation of AI Empowering Mechanical Engineering Teaching

2.1. Dialectical Relationship between Technological Empowerment and the Essence of Education

The application of AI technology in teaching requires a dynamic balance between technological empowerment and the essence of education. On the one hand, AI technology's powerful data processing, pattern recognition, and adaptive decision-making capabilities make it possible to solve the long-standing contradiction between scale and individualization in traditional teaching. Studies have shown that AI-driven adaptive learning platforms can effectively improve students' learning outcomes, and intelligent tutoring systems can intervene to support students' problem-solving processes at the right time. On the other hand, the essence of education is to promote the all-round development of human beings, and technology is always a means to serve this fundamental goal. The practice of Columbia Engineering emphasizes that "we teach students to be critical thinkers, responsible users, and people who can collaborate fluently with AI—that is the goal" [4]. Therefore, the integration of AI technology should focus on expanding rather than limiting the possibilities of learning and enhancing rather than weakening the in-depth interaction between teachers and students.

2.2. Specificity of Mechanical Engineering Teaching and Its Alignment with AI Technology

The teaching characteristics of a mechanical engineering major determine the unique orientation of AI technology application. First, the hierarchical and systematic characteristics of the knowledge system make the curriculum content organization based on knowledge graphs have a natural advantage. The practice of Beihang University shows that constructing a five-level knowledge system graph that accurately covers core knowledge points can customize learning paths for students with different professional backgrounds [5]. Second, the high integration of theory and practice requires teaching to establish an effective connection between abstract concepts and concrete operations. AI-driven virtual simulation and digital twin technologies can simulate the dynamic behavior of mechanical systems in the virtual space, helping students establish a mapping relationship between theoretical knowledge and engineering phenomena. Third, the cultivation of engineering thinking requires a lot of problem-solving practice and immediate feedback, and AI tutoring systems can provide personalized guidance during students' practice to promote deep learning.

3. Restructuring of Curriculum System: AI-Driven Knowledge Organization and Content Update

3.1. Curriculum Content Restructuring Based on Knowledge Graph

Knowledge graph technology provides a powerful tool for the systematic organization of curriculum content in the mechanical engineering major. Through in-depth deconstruction of curriculum knowledge points and clarification of their logical relationships, a curriculum knowledge graph can be established and linked with teaching resources such as micro-video lectures, text test questions, and discussion questions, enabling students to clearly grasp the knowledge context. By systematically sorting out and integrating the key technical points originally scattered in multiple courses, artificial intelligence technology is used to build a dynamic and visual professional knowledge association network, aiming to break the barriers between traditional courses and help students form a systematic and hierarchical professional knowledge structure.

On the basis of the knowledge graph, a hierarchical competency goal graph can be further established, and hierarchical competency goals for each module can be set according to the internalization process of students' mastery of knowledge or skills. At the same time, knowledge learning is placed in problem-solving scenarios. Applied problems are extracted from the complex problems of scientific research projects and engineering projects, and a problem chain including three levels of application, method, and concept is established in accordance with the logic of problem solving, building a bridge from the problem-solving field to the theoretical knowledge learning field.

3.2. Design of "Mechanical + Intelligent" Composite Curriculum System

Facing the new requirements of talent training brought by the intelligent upgrading of the manufacturing industry, the curriculum system of the mechanical engineering major needs to be systematically restructured around the cultivation of "mechanical + intelligent" composite competencies. For example, while retaining basic courses such as Theory of Machines and Mechanisms and Mechanics of Materials, digital manufacturing cases are embedded, interdisciplinary courses such as Fundamentals of Machine Learning and Industrial Internet Technology are added, and a three-level module of "foundation—integration—frontier" is constructed. Among them, the foundation level strengthens core knowledge, the intelligent

integration level adds interdisciplinary courses such as intelligent design and simulation (AI+CAD/CAE) and digital twin and intelligent manufacturing systems, and the frontier expansion level dynamically offers elective directions such as additive manufacturing and intelligent operation and maintenance.

The practical experience of Cornell University shows that integrating AI into mechanical engineering courses is not treated as an isolated topic but as a design and analysis tool that students can immediately apply to practical problems [6]. The unique advantage of mechanical engineers is that they work at the intersection of computing, materials, sensing, manufacturing, and human experience. Therefore, the cultivation of AI literacy should enable students to deeply understand how AI works and think critically about how to integrate it into physical systems, design decisions, and robotics. Table 1 summarizes the impact of AI technology on mechanical engineering teaching.

Table 1: Corresponding Relationship between AI Technology Types and Mechanical Engineering Teaching Elements.

AI Technology Type	Application Scenarios in Mechanical Engineering Teaching	Teaching Value	Integration Mode
Knowledge Graph	Curriculum content organization, knowledge point association.	Help students form a systematic knowledge structure.	Embedded in the curriculum platform, presented visually.
Intelligent Tutoring System	Classroom exercises, after-school homework, problem solving.	Provide immediate feedback and personalized guidance.	Serving as an AI teaching assistant, available 24/7 online.
Virtual Simulation & Digital Twin	Experimental teaching, design practice, process verification.	Break the limitations of physical conditions, enable safe trial and error.	Complementary to physical experiments, realizing virtual-real integration.
Learning Analytics	Learning situation diagnosis, learning path optimization.	Data-driven teaching decision-making, precise intervention.	Background analysis with visual presentation on the front end.
Natural Language Processing	Classroom interaction, report evaluation, literature retrieval.	Improve the quality and efficiency of teaching interaction.	Integrated into the teaching platform to assist teachers and students.

4. Innovation of Teaching Models: Human-Machine Collaborative Classroom Teaching

4.1. Enhanced Classroom Interaction Based on AI Teaching Assistant

AI teaching assistant systems can play multiple supporting roles in classroom teaching. The Department of Chemical Engineering at Columbia University has developed a "novice chatbot" that simulates students' difficulties in understanding concepts by building an AI model with deliberately reduced performance, allowing students to take on the role of teachers to instruct the error-prone AI model, thus achieving more effective learning [4]. This role-reversed teaching design not only deepens students' understanding of knowledge but also cultivates their critical thinking and

communication skills.

In mechanical engineering professional courses, AI teaching assistants can provide real-time examples and visual demonstrations in the theoretical explanation link, offer targeted prompts according to students' operations in the practice link, and guide students to think in depth about multiple solutions to engineering problems in the discussion link. The online course Additive Manufacturing Processes and Equipment at Beihang University relies on an "interactive case agent" to simulate typical scenarios such as topology optimization design, guiding students to analyze practical links such as material selection, process parameters, and defect detection, and carries out advanced discussions combining real engineering cases such as lunar lander structures offline [5].

4.2. Construction of the "Dual-Chain Driven" Teaching Model

A blended online and offline teaching model driven by the "dual chain" based on the knowledge graph is constructed. Online, the panoramic and visual knowledge graph attracts students' attention, and the problem graph creates online learning and inquiry scenarios related to real life, production, and scientific research, closely combining abstract drawing knowledge with mechanical structures in daily life, equipment manufacturing in industrial production, and scientific research projects of the teacher team. Guided by the problem chain, students carry out task-based learning around specific knowledge points, the platform provides real-time feedback on learning outcomes, and it dynamically generates personal learning path graphs.

Offline, a task-chain-driven teaching model based on a knowledge graph for the whole process of "pre-class—in-class—after-class" learning is constructed. Pre-class, students understand the whole process of classroom activities through the task chain and clarify learning tasks and goals; teachers obtain learning feedback through pre-class tasks, understand learning difficulties and bottlenecks, and dynamically adjust in-class teaching plans. In-class tasks realize interactive flipped learning and interactive internalization, and teachers lead students to carry out collaborative learning according to learning situation data, opening up personalized learning paths for individual students in class. After-class, based on the learning data analysis and student stratification suggestions from the knowledge graph, different levels of after-class tasks are assigned, and targeted after-class guidance is carried out.

4.3. AI Empowerment of Project-Driven Teaching

Project-driven teaching is an effective way to cultivate students' comprehensive engineering abilities, and AI technology can play an empowering role in project topic selection, process guidance, and achievement evaluation. Project-driven teaching with "Whole-Process Project Penetration + Virtual-Real Integration" is implemented, with real enterprise projects (such as the development of vision sorting robots) running through the classroom, integrating blended online and offline teaching with digital twin technology, and simulating the dynamics of mechanical systems through virtual mapping. During the implementation of students' projects, the AI system can recommend relevant learning resources according to their progress, identify possible difficulties and provide timely prompts, record key decisions and innovations in the project process, and provide process-based evidence for the final evaluation.

Figure 1 summarizes the innovative framework of the human-machine collaborative teaching model.

5. Upgrading of Experimental Practice: Virtual-Real Integrated Competency Cultivation

5.1. Intellectualization of Virtual Simulation Laboratories

Virtual simulation experiments are increasingly widely used in mechanical engineering education, and the integration of AI technology further enhances their teaching value. By integrating intelligent guidance and adaptive difficulty adjustment functions, virtual simulation experiments can dynamically adjust task complexity according to students' operational levels, ensuring challenge while avoiding frustration. Every operation, parameter adjustment, and wrong attempt of students in the virtual environment can be automatically recorded by the system, forming high-density process data, which provides a basis for analyzing the development trajectory of students' engineering thinking.

Research at Cornell University emphasizes that the latest advances in the field of scientific machine learning are transforming simulations that traditionally take weeks or months to complete into near real-time prediction tools, fundamentally changing the way engineers design, iterate, and analyze systems [6]. Introducing these cutting-edge technologies into teaching enables students to experience the complete design iteration process within limited class hours and understand the impact of different design parameters on system performance.

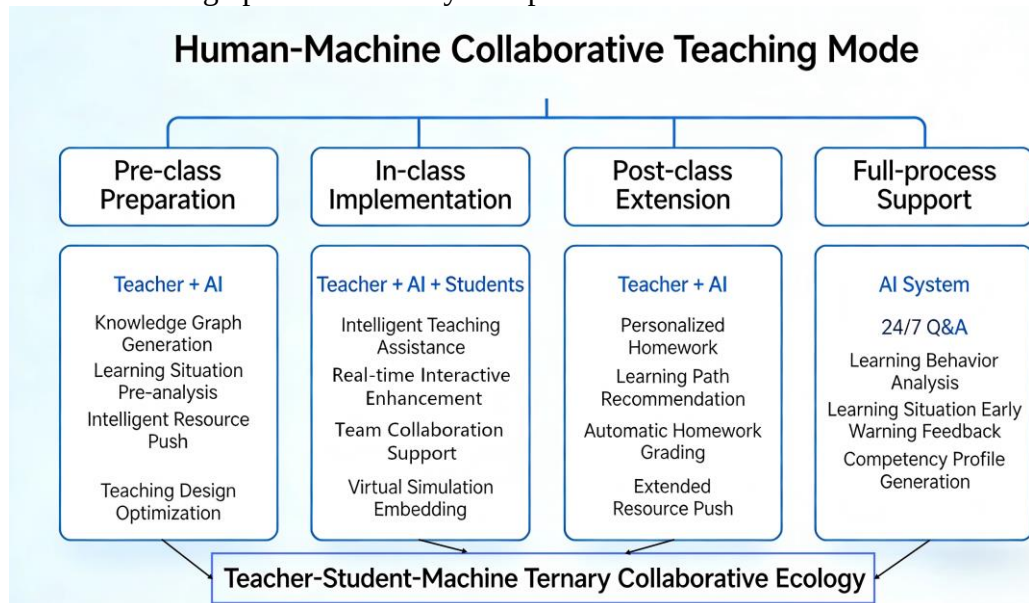


Figure 1: Framework of Human-Machine Collaborative Teaching Model for Mechanical Engineering.

5.2. Digital Enhancement of Physical Experiments

Physical experiment teaching can also benefit from AI technology. By deploying sensors and intelligent monitoring systems on experimental equipment, real-time data of students' operation processes can be collected, the standardization of operations and potential risks can be identified, and immediate feedback and guidance can be provided. The AI system can also automatically evaluate the depth of understanding and thinking quality of students according to the analysis and conclusions in their experimental reports, providing evaluation support for teachers. For example, a three-classroom system of "cloud-based self-learning—smart seminar—virtual-real experience" is constructed to provide matching learning scenarios for students to carry out different forms of learning activities. The organic combination of virtual simulation and physical experiments can not

only break the limitations of physical conditions, allowing students to fully explore through trial and error in a safe environment, but also retain the irreplaceable tactile experience and engineering perception in real operations.

6. Optimization of Learning Support: Data-Driven Personalized Guidance

6.1. Learner Portrait and Learning Path Recommendation

Based on the analysis of learning behavior data, a multi-dimensional learner portrait can be constructed, covering information such as the degree of knowledge mastery, cognitive style preferences, and learning strategy characteristics. For example, constructing a “digital twin of students” enables better understanding and simulation of student needs by capturing systematic trends, thereby offering a test platform for developing next-generation AI tutors while avoiding the exposure of real students to unvalidated systems.

On the basis of learner portraits, the AI system can recommend personalized learning paths for students. The practice of Beihang University shows that constructing a five-level knowledge system graph and customizing learning paths for students with different professional backgrounds, combined with a set of personalized auxiliary instructions, automatically generating syllabi and auxiliary teaching cases according to needs, and supporting homework correction and visual analysis of learning data, all provide support for personalized learning [5].

6.2. Immediate Feedback and Intelligent Tutoring

Providing immediate and accurate feedback during students' learning process is a key factor to promote deep learning. AI tutoring systems can quickly diagnose students' misunderstandings according to their answers or operations and provide targeted explanations and guidance. For open-ended engineering design tasks, although the AI system finds it difficult to give a single correct answer, it can guide students to think about key constraints, weigh different design schemes, and verify the rationality of design results through questioning. The "Socratic AI dialogue system" developed by the Department of Computer Science at Columbia University is designed to promote students' in-depth understanding of complex concepts through guided questioning and adaptive follow-up questions, rather than directly providing answers [4].

7. Challenges and Countermeasures

7.1. Main Challenges of AI Technology Application

The integrated application of AI technology in mechanical engineering teaching faces multiple challenges. From the technical perspective, problems such as the stability of hardware and software systems, the integrity of data collection, and the interpretability of algorithmic decisions still need continuous optimization [7]. From the teachers' perspective, most teachers have limited understanding and application capabilities of AI technology and need systematic training and support. From the students' perspective, over-reliance on AI may weaken the development of independent learning and problem-solving abilities. From the ethical perspective, the collection and use of learning behavior data involves the protection of students' privacy, and algorithmic bias may lead to adverse effects on specific student groups.

7.2. Teachers' Role Transformation and Competency Development

The application of AI technology is not to replace teachers but to promote the transformation of teachers' roles to a higher level. Teachers transform from knowledge transmitters to learning designers, growth mentors, and meaning constructors. This transformation requires teachers to have corresponding data literacy and AI collaboration capabilities—understanding the meaning of learning analytics reports and being able to adjust teaching strategies based on data insights; mastering methods of interacting with intelligent systems and being able to make professional judgments and revisions on system recommendations; and having critical thinking to identify possible biases and limitations of algorithms.

8. Conclusions and Prospects

This paper systematically explores the integration paths and innovative applications of AI technology in the teaching of the mechanical engineering major. The research shows that AI technology can be deeply integrated into mechanical engineering teaching from four dimensions: curriculum system restructuring, teaching model innovation, experimental practice upgrading, and personalized learning support optimization. Curriculum content organization based on knowledge graphs can help students form a systematic knowledge structure; the human-machine collaborative classroom teaching paradigm can enhance the quality and efficiency of teaching interaction; the virtual-real integrated experimental practice ecology provides students with safe and rich engineering experience; and data-driven personalized learning support helps to realize the educational ideal of teaching students in accordance with their aptitude.

Looking forward to the future, the application of AI technology in mechanical engineering teaching will present several development trends. Multimodal learning analytics technology will integrate multiple data sources such as classroom voice, images, and equipment operation logs to achieve a more refined perception and understanding of the teaching process. The application of large language models will make the interaction of intelligent tutoring systems more natural and flexible, adapting to a wider range of learning scenarios. Digital twin technology will realize the deep integration of physical and virtual teaching spaces, providing students with a more immersive engineering practice experience. More importantly, the application of AI technology will shift from assisting teaching to empowering learning, from instrumental rationality to value rationality, and seek a dynamic balance between technological empowerment and the essence of education.

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